Analysis of FFNN Training on CIFAR-10

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1. Training Dynamics

The fully connected feed-forward neural network (FFNN) was trained on CIFAR-10 for **6–8 epochs**. Initially, the network had a hidden layer size of **512 neurons** with **ReLU activation** (5 epochs). After experimentation, the first hidden layer was increased to **1024 neurons** with the same activation function (8 epochs).

- **Loss Trends:**
  Both training and validation losses decreased steadily in the first few epochs. Small bumps in validation loss were observed due to mini-batch fluctuations and the limited size of the validation set (5,000 images).
- **Accuracy Trends:**
  Training accuracy rose quickly, reaching ~51% with the original settings. Validation accuracy was slightly lower (~52%). After increasing hidden layer size and epochs, the final validation accuracy improved to ~51% while the training accuracy was ~54%.
- **Time/Epoch Considerations:**
  Larger hidden layers increased computation per epoch but required only a few additional epochs to converge.

```
Epoch 1/6, Train Loss: 1.7694, Train Acc: 37.11%, Val Loss: 1.5898, Val Acc: 44.50%
Epoch 2/6, Train Loss: 1.5994, Train Acc: 43.30%, Val Loss: 1.4980, Val Acc: 47.22%
Epoch 3/6, Train Loss: 1.5185, Train Acc: 46.39%, Val Loss: 1.4487, Val Acc: 48.94%
Epoch 4/6, Train Loss: 1.4652, Train Acc: 48.02%, Val Loss: 1.4296, Val Acc: 50.06%
Epoch 5/6, Train Loss: 1.4217, Train Acc: 49.52%, Val Loss: 1.4159, Val Acc: 50.98%
Epoch 6/6, Train Loss: 1.3897, Train Acc: 50.62%, Val Loss: 1.3815, Val Acc: 52.08%
```

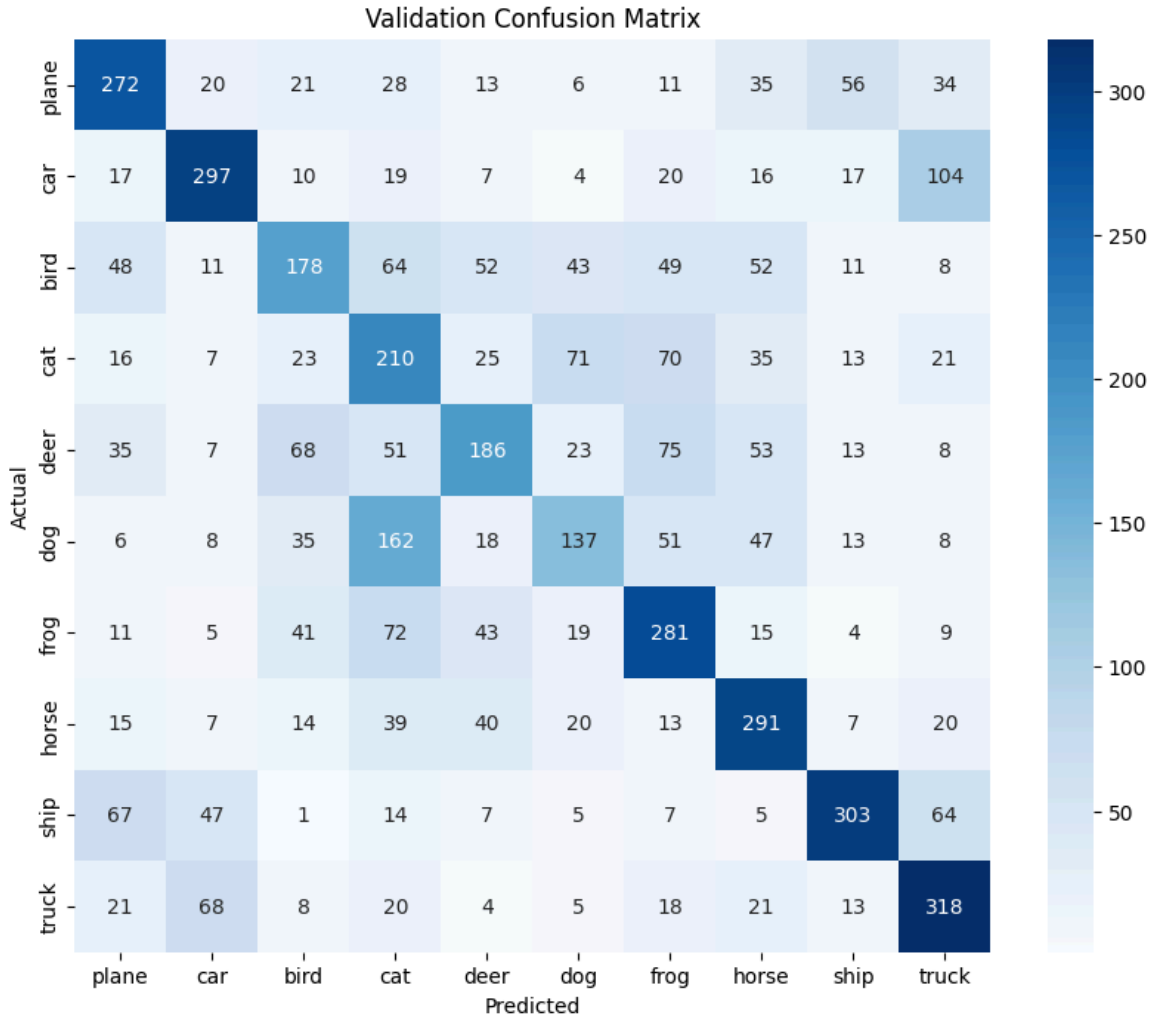
```
Epoch 1/8, Train Loss: 1.7471, Train Acc: 38.17%, Val Loss: 1.6019, Val Acc: 43.40%
Epoch 2/8, Train Loss: 1.5743, Train Acc: 44.29%, Val Loss: 1.5052, Val Acc: 47.34%
Epoch 3/8, Train Loss: 1.4998, Train Acc: 47.09%, Val Loss: 1.4588, Val Acc: 48.10%
Epoch 4/8, Train Loss: 1.4442, Train Acc: 48.86%, Val Loss: 1.4499, Val Acc: 49.66%
Epoch 5/8, Train Loss: 1.4000, Train Acc: 50.31%, Val Loss: 1.4436, Val Acc: 49.80%
Epoch 6/8, Train Loss: 1.3610, Train Acc: 51.48%, Val Loss: 1.3955, Val Acc: 52.08%
Epoch 7/8, Train Loss: 1.3196, Train Acc: 53.18%, Val Loss: 1.3967, Val Acc: 51.86%
Epoch 8/8, Train Loss: 1.2827, Train Acc: 54.14%, Val Loss: 1.3976, Val Acc: 51.14%
```

2. Confusion Matrix Trends

A confusion matrix was computed on the validation set. Key observations:

- **Well-classified classes:**
  - Vehicles like `truck`, `ship`, and `car` (diagonal values: 318, 303, 297) and animals like `horse` (291) and `frog` (281) were classified accurately.
- **Confused classes:**
  - `Cat`, `dog`, `deer`, and `bird` had frequent misclassifications.
  - Notably, cats were often predicted as dogs (71) or horses (70), while dogs were misclassified as cats (162) and horses (51).
  - Cars and trucks were confused with each other (104 car→truck, 68 truck→car).

These trends reflect the FFNN's limitations: without convolutional layers, spatial features are not explicitly captured, making visually similar objects difficult to separate. Misclassified images confirmed this, showing rotated, occluded, or low-contrast objects as common sources of error.



3. Effects of Changes

- **Increased hidden size (512 → 1024):**
  More neurons increased the network's representational capacity, allowing it to capture more complex patterns. Training was slightly slower but final validation accuracy improved.
- **Increased epochs (6 → 8):** Training for more epochs allowed the network to continue improving its accuracy and reducing loss. Early epochs showed rapid learning, while later epochs led to smaller incremental gains, indicating the network was approaching convergence. This longer training slightly decreased final validation accuracy (~1% lower than at 6 epochs).

4. Summary

The FFNN was able to learn meaningful representations from CIFAR-10, achieving reasonable accuracy given its fully connected architecture. Increasing hidden size and using LeakyReLU positively impacted learning, improving final validation performance and stabilizing training. Confusion matrix and misclassified image analysis highlighted that visually similar classes, particularly animals and vehicles, remain challenging for FFNNs due to their inability to exploit spatial hierarchies, a task better suited for convolutional networks.